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Effectiveness of wire netting fences to prevent animal access to road infrastructures: an experimental study on small mammals and amphibians

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Abstract

Transport infrastructures, such as highways, disrupt animal migrations and cause roadkill. To mitigate the latter problem, fences have been built but their effectiveness has rarely been tested under controlled conditions. Here, we tested the effectiveness of the most commonly used fence in France and probably in Europe (wire netting fence) to block animals. We tested the wire netting fence, with and without a structural modification (i.e. an overhang), with three small mammalian species (the European hamster: *Cricetus cricetus* Linnaeus, 1758; the common vole: *Microtus arvalis* Pallas, 1778 & the wood mouse: *Apodemus sylvaticus* Linnaeus, 1758) and two amphibian species (the marsh frog: *Pelophylax ridibundus* Pallas, 1771 & the European green toad: *Bufotes viridis* Laurenti, 1768). During testing, all small vertebrate species tested were placed into an arena, from which they could only escape by crossing the wire netting fence. Without an overhang, almost all adult individuals of all tested species were able to climb over a 30 to 40 cm high wire netting fence. Furthermore, the addition of an 8 cm long overhang at the top of the fence stopped the amphibian species tested but not the most agile mammalian species, such as the hamster and the wood mouse. Based on these results, we do not support the construction of wire netting fences along roads as a measure to stop small animals from crossing. We recommend the use of more effective and durable fences, which, in addition, can be associated with wildlife passages to reconnect isolated populations.

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Keywords
Amphibians, fences, roadkill, small mammals

Introduction

Millions of animals around the world are killed daily by wildlife-vehicle collisions, affecting populations of most taxa (Bruinderink and Hazebroek 1996; Laist et al. 2001; Rao and Girish 2007). Even on roads with only moderate traffic, roadkill can severely impact population viability (Eigenbrod et al. 2007). These impacts can be accentuated in highly modified landscapes, when terrestrial fauna has to cross roads on a daily basis and/or during dispersion and migration movements (Billeter et al. 2008; Bissonnette and Rosa 2009). To limit roadkill, different mitigation measures, such as the construction of fences and wildlife passages, have been implemented, especially in industrialized regions (e.g. Australia, Western Europe and North America). Initially installed to limit vehicle collisions with large mammal species, like ungulates (e.g. deer, wild boar), the primary aim of fence construction concerned human safety and the limitation of economic losses associated with these collisions (Romin and Bissonette 1996; Schwabe et al. 2002; Forman et al. 2003; Bouffard et al. 2012). The installation of fences on both sides of the road or along railways is not mandatory but global recommendations advise such measures, if the risk of collision and/or wildlife mortality is high (Iuell et al. 2003). Large-fauna fences or wire netting must be tall enough to prevent animals from jumping over it (i.e. >1.8 m, Iuell et al. 2003; Morand and Carsignol et al. 2019), while mesh size of such fences is typically relatively large (in general greater than 60×60 mm).

When research demonstrated the major role that roads play in habitat fragmentation and its negative impact on the populations of many species (and not only large mammals), further mitigation measures were implemented. These mitigation measures are designed to reduce roadkill (i.e. fences) and restore population connectivity (i.e. wildlife passages) to allow safe movements on different parts of the habitats separated by the road for various small fauna, such as reptilian (turtle), amphibian (frog and toad), small (shrew) and medium-sized mammalian species (hares, foxes, badgers, etc.) (Aresco 2003; Glista et al. 2009; Klar et al. 2009; Jarvis et al. 2019; Plante et al. 2019). For these species, different fences (made from wire netting, concrete, PVC or metal) were designed and often installed alongside the large-fauna fences. In Western Europe, wire netting fences (with a typical mesh size of 6.5×6.5 mm and a height of 40 to 60 cm) are most often used to block small fauna, and are usually attached to the large-fauna fences (Iuell et al. 2003; Puky 2003; Beebee 2013; Morand and Carsignol et al. 2019). Similar to the large-fauna fences, these small-fauna fences coupled with a wildlife passage are needed to manage the reconnection of populations in areas of high biodiversity (Clevenger et al. 2001; Iuell et al. 2003; Beebee 2013; Testud and Miaud 2018).

Some species are more sensitive than others and require special attention during the planning of infrastructure, such as roads. For example, amphibians are particularly

vulnerable to roadkill due to their mass migration strategy (Joly 2019; Cayuela et al. 2020) and their immobility when facing motor vehicles (Gibbs and Shriver 2005; Mazerolle et al. 2005). Amphibians are of particular concern, since globally 41% of all amphibian species are threatened with extinction (IUCN 2021). Small mammals are also of concern, since they often use the side of roads as refuge, especially in a highly modified landscape (Ruiz-Capillas et al. 2013; Jumeau 2017). While the impact of road mortality on populations of these small mammalian species may not appear problematic, because their population densities are generally high, this is not always the case. Studies show that some of these species are declining at an alarming rate and are now considered endangered, like the garden dormouse (*Eliomys quercinus*) or the European hamster (*Cricetus cricetus*) (Surov et al. 2016; Bertolino 2017). Hence, roadkill of wildlife is an important issue that has to be addressed in an overall conservation strategy (O'Brien 2015; Pinot et al. 2016).

Research objectives

To avoid roadkill of various small-fauna species, such as amphibian and small mammalian species, road managers in Western Europe frequently install wire netting fences alongside roads. Because of their low costs and easy installation, they may seem an attractive measure in roadkill prevention. However, to the best of our knowledge, the effectiveness of such fences to stop amphibian and small mammalian species from entering the road has rarely been tested under controlled conditions (Dodd et al. 2004; Woltz et al. 2008; Brehme et al. 2021). The goal of our study was to experimentally test the effectiveness of wire netting fences to block small fauna, preventing passage into roads. We hypothesized that a wire netting fence will not be appropriate for "agile" species, which might be able to climb the fence (e.g. mice) or jump over it (e.g. frogs), while it will be effective for other species (e.g. hamsters, voles). We further hypothesized that the inclusion of an overhang (i.e. back-bending the top wire netting) will improve its effectiveness. Finally, our study focused on the effectiveness of fences to stop animal road crossing, while studies investigating the effectiveness of such fences in guiding animals towards wildlife passages are lacking and should be encouraged.

Materials and methods

Protocol

This study presents the combined results from four independent experiments that were conducted between 2015 and 2020. While the individual protocols and the group of individuals used (adults/juveniles) differed to some degree between studies, they all shared the same general principle. In each study, individuals were placed in an arena for a pre-determined duration, from which they could only exit by crossing the fence

under investigation. During that period, animals were monitored continuously with an infrared video-camera, so that individual behaviour and the success or failure of passage could be determined.

All studies used a wire netting fence with a mesh size of 6.5×6.5 mm. However, studies differed with respect to fence height (30 or 40 cm, which corresponds to the height typically found along roads in Alsace), the presence or absence of an overhang and its length (from 2 to 15 cm), the tested species, the number of individuals used per test, and the time given to individuals to escape the arena (30 min, 10 or 12 hours). The latter was due to behavioural differences between species and the requirements imposed by the various capture and ethical permits. (Table 1; see Suppl. material 1, for the exact protocol of each study). With the exception of the study concerning the European hamster, the length of the overhang was varied to test its effect on passage success. The greatest length of the overhang was tested first (15 cm or 10 cm, depending on the study) and decreased gradually in subsequent trials, once all individuals had been tested for a given length. Given the nocturnal activity patterns of the tested species, all experiments were conducted during the night, spanning the summers from 2015 to 2020.

Species were selected according to their mode of locomotion. The following species were tested (Table 1): (1) two small mammalian species, considered to be 'non-agile', the European hamster and the common vole, both of which are good runners but have limited jumping abilities; (2) one 'agile' small mammal, the wood mouse, which has good climbing and jumping abilities; (3) one 'agile' amphibian species, the marsh frog, with good jumping abilities; and, lastly, (4) one 'non-agile' amphibian species, the European green toad, which has limited jumping abilities. All tested individuals were captured from the wild for the purpose of the concerned study, except hamsters, which came from a local breeding centre. However, only European green toads were maintained in captivity after capture (for 3 and 15 days for juveniles and adults, respectively, since they participated in a further study). All other captured species were released immediately after the end

Table 1. Summary of the species tested and experimental set-up (for more details, see SM).

Species	Origin of animals	N	Height of netting fence tested (cm)	Length of the overhang (cm)	Body length (mean±SEM) cm	Duration of experiment	Number of animals tested simultaneously
European hamster	Laboratory	26 (5♀ adults 8♂ adults & 13 juveniles)	40	8	25.17±2.00 (adults) 19.88±1.37 (juveniles)	12 h per individual	1
Common vole	Wild	40 adults of each species (8 for each overhang length)	30	0, 2, 5, 10, 15	9.16±0.68	30 minutes per individual	1
Wood mouse	Wild	40 adults (8 for each overhang length)	30	0, 2, 5, 10, 15	9.48±0.70	30 minutes per individual	1
Marsh frog	Wild	40 adults (8 for each overhang length)	30	0, 2, 5, 10, 15	No data.	30 minutes per group	8 adults
European green toad	Wild	39 (9♂ adults & 20 juveniles), the same for both the 0 or 10 cm overhang	40	0 or 10 (only for adults)	5.94±0.67 (adults) ~ 1 cm (juveniles)	10 hours per group	9 for adults & 20 for juveniles

of testing. The total number of individuals that could be used for experimentation was limited by capture/ethical permits. Before experimentation, individuals were measured and weighed, and sex was determined in all species tested, except marsh frogs. The capture and housing protocols are detailed in the Suppl. material 1. All manipulations were carried out after obtaining the legal authorizations for capture and transport, and the approval of the different protocols by the Ethical Committee (see Suppl. material 1).

Methods

Each time an individual was placed in the arena, alone or with conspecifics, the result of the passage test was recorded either as success (if the individual successfully crossed the fence by climbing or jumping over it) or as failure (if the fence was not crossed). For each overhang length tested, the proportion of crossing success (mean±SEM) was calculated for all individuals tested at that specific overhang length. In the case of the European hamsters and European green toads, test results from adult and juvenile animals were kept separate. For both amphibian species, animals were tested as groups, which prevented to recognize the crossing success of individuals. Given the differences in the experimental protocol of the various species (i.e. individual/group testing, presence/absence and dimensions of the overhang), we present results from all experiments without statistical testing. Nevertheless, we believe that the results are explicit, even in the absence of statistical analysis.

Results

Effectiveness of wire netting fences

Without an overhang, all species were able to cross the fence. The crossing success rate varied between 45% for juvenile green toads and 100% for wood mice, marsh frogs and adult green toads (Table 2). Hamsters were not tested without an overhang. Since crossing success rate of juvenile hamsters was 100% for a fence with a 10 cm overhang

Table 2. Crossing success rates for wire netting fences.

Species	Locomotion type	Status	Fence height	Crossing success without overhang	Crossing success with an 8/10 cm overhang
European hamster	Running$^+$	Adult	40 cm	NA	80%
	Running$^-$	Juvenile	40 cm	NA	100%
Common vole	Running$^-$	Adult	30 cm	87.5%	0% (25% at 15 cm)
Wood mouse	Climbing$^+$/Jumping$^+$	Adult	30 cm	100%	75% (100% at 15 cm)
European green toad	Jumping$^-$	Adult	40 cm	100%	0%
	Jumping$^-$	Juvenile	40 cm	45%	NA
Marsh frog	Jumping$^+$	Adult	30 cm	100%	0%

Without overhang, wire netting fences of 40 cm are not effective to stop the tested small mammals and amphibians. With a 10 cm overhang, the European hamster, Common vole and the Wood mouse can still climb over these fences. The '+' and '-' signs indicate the capabilities of the species, with the '+' sign indicating better performance than the '-' sign.

(and 80% for adult hamsters; Table 2), it is likely that both juvenile and adult hamsters would have crossed the fence lacking an overhang without problems. For the other species, the presence of an 8–10 cm overhang decreased the crossing success rate to 0% for green toads and common voles, but only to 75% for wood mice (Table 2).

In marsh frogs, crossing success dropped (from 100% to 12.5%) when the overhang reached a length of 5 cm and became zero at a 10 cm overhang. For the common vole, the introduction of an overhang reduced the crossing success substantially but some individuals were still able to cross the fence with a 15 cm overhang. The length of the overhang had little effect on the crossing rate of wood mice, which passed even at the greatest length tested.

How animals crossed the fence

Seven of the 20 juvenile green toads tested were able to pass through the 6.5 mm mesh of the wire netting. All other individuals of this species and all individuals of the other species tested that managed to pass the fence, did so by climbing it and not by jumping over it. European hamsters (the largest species tested) were able to pull themselves up onto the overhang by grabbing the end of the overhang and pulling themselves up using their front legs (i.e. without climbing along the overhang), once they reached the top of the fence. The same occurred in wood mice up to an overhang length of ~10 cm. For longer overhangs, wood mice climbed along the overhang, upside down, until they reached its far end, where they passed. The same behaviour was occasionally observed in juvenile hamsters.

Discussion

Our study, which experimentally investigated the effectiveness of wire netting fence to stop small terrestrial vertebrates (five species of small mammals and amphibians) from entering into road infrastructures, clearly demonstrates the limitations of such structures.

Without an overhang at the top of the wire netting fence, individuals of all tested species, adults and juveniles, were able to pass the structure. Clearly, wire netting fences without overhang should be avoided in future constructions. Furthermore, even the addition of an overhang only marginally increased the effectiveness of the wire netting fence in blocking the tested mammalian species. Individuals of all small mammal species tested were still able to cross the fence, including the common vole despite some difficulties, even with a long, 15 cm overhang. For example, hamsters were sufficiently large to reach the far end of the overhang, so that they could pull themselves up and cross the fence. However, some adult individuals were unable to cross the fence, which was likely explained by their body condition (i.e. these were the largest and heaviest adult hamsters). Since the hamsters tested were captive individuals from a breeding center, they were presumably fatter and less agile than wild hamsters. Wood mice were

able to reach the far end of the overhang by climbing along the mesh, upside down. However, changes in the design of the overhang structure, like the use of a solid structure (e.g. a metal plate), without gripping possibility, might prevent such small/agile species from crossing. Nevertheless, structures similar to the ones used in our study should be avoided, at least for small mammals.

By contrast, for amphibians, the tested wire netting fence might prove effective when combined with a 10 cm overhang. Adult individuals of European green toads and marsh frogs were unable to pass such a structure during our tests. However, since juvenile frogs were able to pass through the mesh of wire netting fences, even at a relatively small mesh size, their use should be avoided at the proximity of ponds. They should also be avoided when more "agile" amphibians, such as achieved jumping (i.e. Agile frog, *Rana dalmatina*) or climbing species (i.e. European tree frog, *Hyla arborea* or newts) are present. These species were not tested in our study but have been shown to easily cross a 40 cm concrete fence (Conan et al. 2021).

Given our current test results, we suggest to avoid the use of wire netting fence along motorways. In eastern France, 70.4% of overhangs of wire netting fences along motorways inspected by Jumeau (2017) had a length of less than 9 cm, which is lower than the 10 cm overhangs that proofed effective for the tested amphibians in our study. The author explained this situation by a lack of information/communication on behalf of the work crews installing these fences along the roads. If during construction the fences were buried a few centimetres too deep, while fence height above ground was maintained, bending the top of the fence resulted in a too short overhang. In addition, the author reported that 78.2% of inspected fences, even recently built fences, showed signs of deterioration, such as broken mesh, too high vegetation (allowing animals to climb over the fence; Arntzen et al. 1995), as well as deteriorated or absent overhang. These results are especially troubling, since such a state will also reduce the effectiveness of fences for their second role, namely to guide animals to wildlife passages (Clevenger et al. 2001; Beebee 2013; Testud and Miaud 2018).

For several years, studies have highlighted the ineffectiveness of wire netting fences in excluding animals from road infrastructures, especially for amphibians (Schmidt et al. 2008; Testud 2020). Nevertheless, these fences are still being used along newly built roads, even when they are located in the dispersal corridors of endangered species (e.g. green toad and European hamster in Alsace, France). Therefore, we recommend that these fences should be replaced by viable alternatives. Opaque fences, for example, may be more effective in guiding small animals to the wildlife passages, and experimental tests to confirm this are urgently needed. It is, however, important to note that effective fences can impact the movement of individuals on both sides of a road and consequently lead to a decrease in gene flow if individuals are unable to reach wildlife passages (e.g. newt; Matos et al. 2018). In this context, testing the effectiveness of structures to guide animals to wildlife passages is needed in controlled and field conditions while an increase in the number of wildlife passages might also be necessary.

Conclusions

Wire netting fence between 30 and 60 cm is a commonly used mitigation device to prevent small vertebrate species from entering/crossing roads and reduce roadkill. This study showed that its effectiveness is very limited. Accordingly, we suggest that this device should be avoided and replaced by more effective and durable fences.

Ethics approval

All manipulations were carried out after obtaining the legal authorizations for capture and transport (2019-DREAL-EBP-0031) and a certificate permitting the detention of wildlife species in captivity (DDPP67-SPAE-FSC-2019-04). The experimental protocol was approved by the ethics committee (CREMEAS and Ministry) under the agreement number (#18546-2019011810282677 v7).

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Supplementary material 1

Supplementary materials and methods

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Explanation note: In the following we provide details for the four separate studies conducted. Each study used a different experimental set up, which was adapted to the species tested.

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